Is this Artwork Original or Is it a Copy? The Answer by a New Anti-Counterfeiting Tag

We present a patented apparatus which consists of an extreme ultraviolet radiation source writing invisible patterns on thin tags of alkali halides. The tags written using this method are almost impossible to counterfeit, and offer a much better protection against fakes than the available anti-counterfeiting techniques. So far, we have used this invisible marking to tag electrical components, credit cards and containers of radioactive wastes. However, the protection level, the cost and the production yield associated with our technique suggest that the ideal field of application is the traceability and the protection of artworks against fakes

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Introduction

Counterfeiting is a global problem that has major social and economic consequences [1]. The spread, number and kind of counterfeit goods has greatly increased in recent years. In a recent update [2] the Organization for Economic Co-operation and Development has estimated in USD 250 billion in 2007 the worldwide value of international trade in counterfeit goods, with an impressive growth rate of USD 25 billion/year. The above estimate does not include counterfeit and pirated products that are produced and consumed domestically, nor does include the significant volume of pirated digital products that are being distributed in the Internet.

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The range of products has broadened from luxury objects to products directly impacting on health and safety, like food, pharmaceutical products and automotive/aerospace spare parts. Consequently, anti-counterfeiting (AC) technologies are continuously evolving, extending their applications to identification of the origin of documents or objects, copyright protection systems, traceability and identification of paper currency, identity/credit/debit cards, forensic documents, critical/strategic components, dangerous wastes, pharmaceutical products.

Concerning artworks, 4,222 faked works of art have been found in Italy by the 'Comando dei Carabinieri Cultural Heritage Protection' just during the first six months in 2012. The value of the counterfeited artworks discovered in the last four years was 250 million euro [3], but a conservative estimate of the market of counterfeit artworks was about 1,5 billion euro during the year 2011.

Many AC techniques based on high-tech tagging have been developed, like fluorescent inks (currently used, e.g., in banknotes), thermo-chromic inks (used,

e.g., for tickets of events and lottery), demetallized hot stamping foils, holograms, diffractive foils, laser engraving (writing inside glasses) and radiofrequency identifiers. However, each of these techniques has its own effectiveness and lifetime limited by a variety of factors, including the ability of counterfeiters to replicate the technique, so that a continuous innovation of AC technologies is needed. Most important, none of the above techniques contemporarily matches a demanding way for a difficult-to-replicate marking and a simple control reading, being at the same time respectful of the privacy issue.
We propose here a new invisible marking technology to tag critical and/or expensive goods, which is effective to fight counterfeiting using a technology whose complexity and cost can be tailored to the value of the good to be protected and leaving, on the other hand, the specific reading technique straightforward.

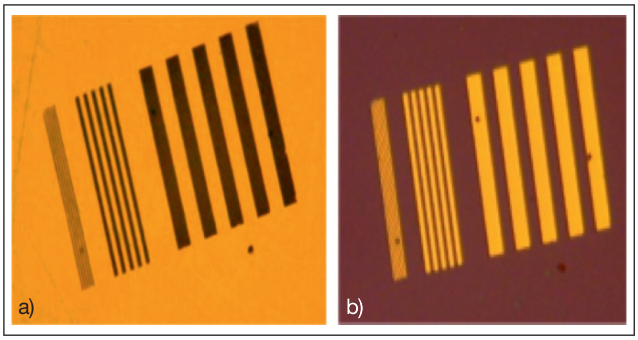

FIGURE 1 a) Luminescent patterns on a LiF crystal obtained by placing a mask in contact with the crystal surface and exposed to EUV radiation in vacuum. b) The mask, here observed in reflection mode, is a silicon nitride membrane patterned by sequences of 100-nm-thick gold zones with 2, 6 and 20 μm periods
Source: ENEA

Technology Background

At the ENEA Research Centre in Frascati we have developed expertise in the field of extreme ultraviolet (EUV) radiation and soft X-rays generation and applications [4]. A plasma source driven by two different XeCl excimer lasers is operative and its short-wavelength radiation is used in different fields, ranging from microscopy to radiobiology, from micro-radiography to photonics. Based on our laser-plasma source, we have developed an apparatus for EUV projection lithography that was recently put in operation, printing a sub-100-nm-resolution pattern on polymethylmethacrylate (PMMA) resist [5, 6].
More recently, we operated a discharge-produced-plasma source (DPP) which can deliver EUV pulses with energy/solid angle of 20 mJ/ster in the 10-20 nm wavelength spectrum and 60 mJ/sr/shot in the full EUV range, working up to 20 Hz repetition rate [7]. The DPP is particularly suitable to irradiate large-sized targets in the near field with a higher yield vs. laser-plasma source, thus showing its superiority in the EUV contact lithography irradiations. As an example of typical space resolution attainable by EUV contact lithography, Fig. 1a shows a luminescent pattern based on stable color centers locally written on a lithium fluoride (LiF) crystal.

The Invisible Marking Technique

Besides affecting the chain bonds of polymers like PMMA, the EUV radiation also alters the electronic structure of a class of dielectric materials, like alkali halides. Depending on the EUV irradiation conditions, a permanent visible pattern on alkali halides can be obtained, see Fig. 1 However, in particular conditions the radiation can locally produce a controlled density of color centers, thus printing a trace which is invisible to the naked eye and also at the microscope observation.
Thanks to the atomic-scale interaction and to the short EUV wavelengths, the writing process allows to achieve an extremely high spatial resolution of the stored image, down to the sub-micrometer scale [8] which is not attainable, e.g., using fluorescent inks deposited by the current ink-jet printer technology.
The invisible mark created by EUV radiation on the alkali halide can be detected by a proper reading system, suitable for the specific luminescent material. Figure 2 shows a pattern printed on a LiF film by contact EUV lithography (namely, an hexagonal-holes mask in contact with the material), as observed by an

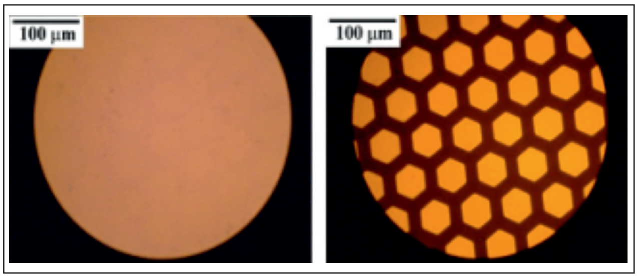

FIGURE 2 Hexagonal-hole pattern obtained by contact EUV lithography and observed at an optical microscope by white light (left) and by using the dedicated reading technique (right)
Source: [11]

optical microscope using a conventional illumination and when using the dedicated optical device. The LiF film was thermally evaporated on a glass substrate at the ENEA Research Centre in Frascati [9].
Figure 2 shows the color centers patterned by EUV radiation and a contact mask, which becomes visible only by the specific optical excitation and spectrally selected fluorescence spectra. The apparent similarity with the behavior of some fluorescent inks fails at a deeper analysis, thanks to the very low absorption of color centers in the ultraviolet, which, on the contrary, is strongly absorbed by inks, see Fig. 3. A simple, differential spectral reading system can thus definitely distinguish between a mark written by our technique and the same mark written by fluorescent ink.
The security level of our technology can be further increased by the digital encoding of the image, applying the current state-of-the-art cryptography techniques. In this case, the control relies not only on the physical reading of the image, but also on its decoding with the appropriate digital key/algorithm.
A prototype of a portable device able to read the invisible marks through a PC interface is shown in Fig. 4. In this case an encoding technique has been applied to crypt the invisible pattern. The PC screen shows the hidden raw data matrix (an array of tiny squares as a 2-D barcode) written on the film as read by the device, and the corresponding pattern "WATER MARKING" decoded by a dedicated software.
We can further increase the security level of our technology by structuring the crystalline film in a series of thin layers, each separated by non-luminescent materials, with a variable tapered thickness. By so doing, after irradiation by ionizing radiation, the energy of the ionizing radiation affects the luminescence ratio of the different layers, and therefore a mark imprinted with an ionizing radiation having a different spectral energy with respect to a pre-determined one can be identified.
ENEA has filed two patents about the invisible marking system [10].

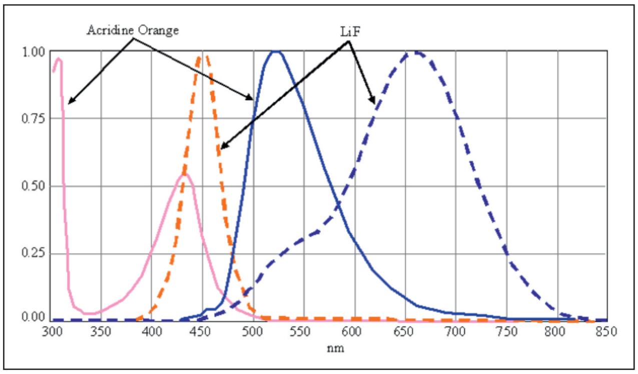

FIGURE 3 Optical absorption and emission spectra of LiF color centers (dashed lines) and of Acridine orange (continuous lines) in the range 300 nm - 850 nm. Acridine orange is the dye having the most similar absorption and emission spectra vs. LiF
Source: ENEA

Application to Artworks

In the past, we tested our invisible writing technique to produce tags able to track radioactive wastes, and to protect cards and electronic components [11]. To test the possible exploitation of our technology for AC purpose on artworks, we need adhesive and transparent tags. To this end, we have deposited a LiF film on transparent and adhesive plastic substrates. We printed the schematic picture of a Li atom on these tags in advance with respect to the LiF film deposition on the "nucleus" of the atom picture. Then, we irradiated the tags to write the invisible letter "E" within the pictured nucleus of the Li atom. The results, shown in Fig. 5, demonstrate the capability to produce flexible and adhesive AC tags that can be applied to every surface, independently of its roughness.

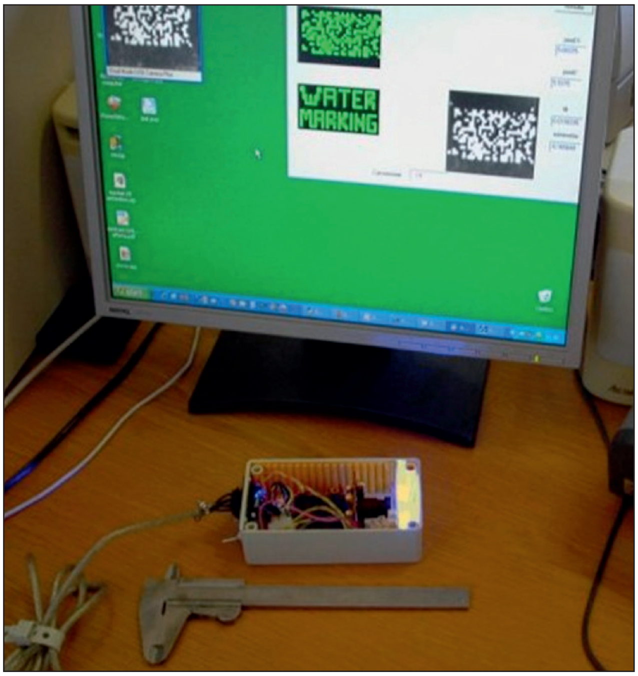

FIGURE 4 Prototype of a portable reading device able to detect the invisible images placed on a desk. On the PC screen there is the coded data matrix (a 2D binary array) transmitted by the ENEA device as read on the irradiated film, and below the corresponding sign "WATERMARKING" as decoded by a specific software
Source: ENEA

Obviously, a good anti-counterfeiting tag should change its status/ pattern-visibility when it is torn off the original object, in order to easily recognize if it has been moved to a faked object. We have checked what happens when slowly and carefully pulling off the adhesive tag of Fig. 5 and attaching it to another surface. The result, shown in Fig. 6, shows that the letter "E" patterned by EUV radiation becomes visible when observed at ambient light after the tag was pulled off the original surface.
As a test to check the applicability of our AC tags to archaeological objects, we stuck a tag like that of Fig. 5 to a copy of a bronze statue, known as "hero four-eyes and four-arms", see Fig. 7. The original statue was found in the Nuraghe Village at Abini (Nuoro, Sardinia) and dated back to the tenth century B.C.
Figure 7 provides evidence that the patterned letter E is absolutely invisible to the naked eye, while it is easily detected by a proper illumination and filtering.

Towards the Market: Durability, Cost and Production Yield

When seeking for practical uses of our technology, an important issue is the durability of the invisible writing on AC tags. In general, LiF is a rugged

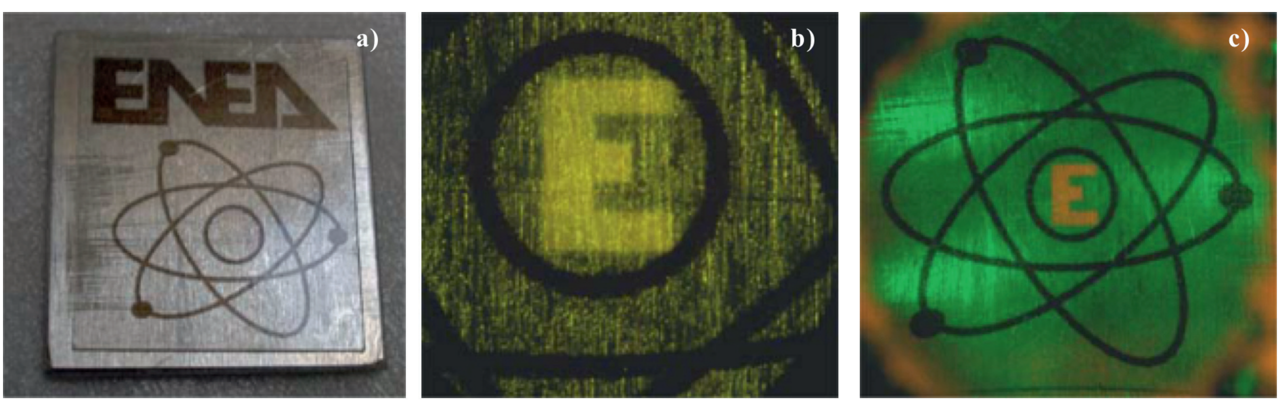

FIGURE 5 Transparent and adhesive plastic tag stuck to a rough metal plate. The LiF film is deposited in the area corresponding to the central "nucleus" of the atom pictured, and then it is exposed through a mask (where the letter "E" was patterned) to the EUV radiation emitted by the ENEA DPP. a) The tag observed at ambient light. b) The tag observed by a microscope at low magnification (2.5× objective) using the appropriate illumination and filtering. Note the rough surface of the metal plate, well visible behind the tag. c) The tag observed by the patented portable reading device
Source: ENEA

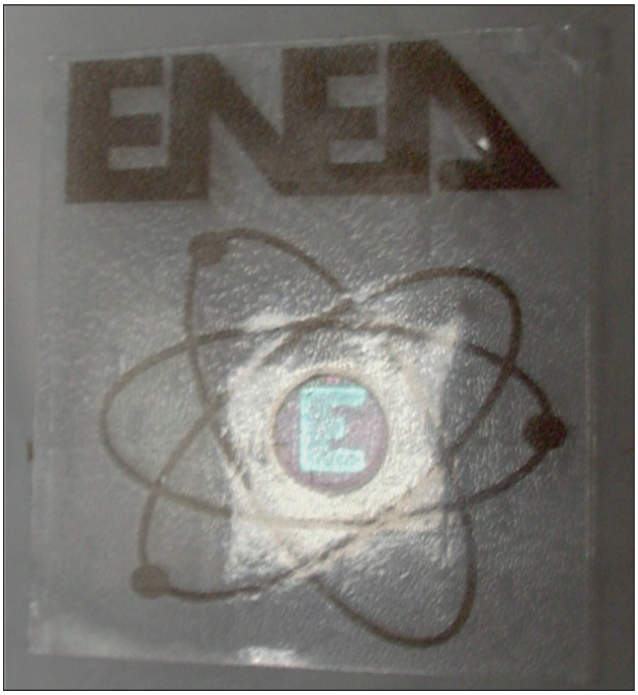

FIGURE 6 The same adhesive tag of Fig. 5a photographed after being pulled off the original metal substrate and re-attached to another surface. The patterned letter E, which was invisible, see Fig. 5a, is now visible at ambient light illumination
Source: ENEA

material, hard and almost non-hygroscopic. Our tests show that the irradiated films can be touched many times without significantly damaging or altering the visibility of the pattern, as detailed in [11]. When the tags are exposed to severe conditions (heavy and uncontrolled scratching or abrasions), a protection film can be applied on the tag.
What does a Company need to build up an industrial prototype producing our AC tags? a) The ENEA patents and the related know-how; b) A 50-W average power EUV source (DPP commercially available); c) A contact mask with the barcode/logo/picture (made, e.g., by lithography, or using a laser, or by chemical erosion); d) A suitable alkali halide film sensitive to EUV deposited on a flexible transparent plastic substrate (commercially available).

There are several parameters that influence the number of tags written per unit time, including the time to accurately align the contact masks on tags, the maximum number of tags that can be irradiated in the same irradiation run, and the area to be irradiated (which depends on the size of the patterns). A conservative estimation, based on a system made by assembling commercially available parts, gives a potential production yield of about 50-100 tags/hour, each tag having a patterned area of 0.4 cm^2.

Summary and Remarks

ENEA has developed and patented a new anti-counterfeiting/tracking technology based on EUV lithography on luminescent materials. An arbitrary pattern can be transferred as an invisible image on thin tags, which in turn can be put on or embedded in any object to be protected or traced. A compact and cheap device can read the luminescent image and check the authenticity of the tags.
In contrast with the use of fluorescent inks, our patterns are obtained by illumination of alkali halides materials with EUV radiation rather than by ink jet writing. Consequently, our patterns can reach a better spatial resolution (down to the sub-micrometer range), and they can be easily distinguished among fluorescent-ink patterns because of the different spectral response to UV light illumination (see Fig. 3).
Our writing tool is complex and expensive (especially in the case of projection imaging, giving sub-micrometer resolution) and it requires an experienced and skilled team to be optimized. As a consequence, it is highly unlikely that a counterfeiter can build up and operate a similar writing tool. On the other hand, the reading system is cheap and simple so that anybody can easily check the presence of watermark patterns to verify if the good is genuine.
The complexity and safety level of our hidden patterns can be further enhanced and adjusted by encoding patterns by cryptography techniques, and/or by structuring the fluorescent film as a series of thin layers, each separated by non-luminescent materials,

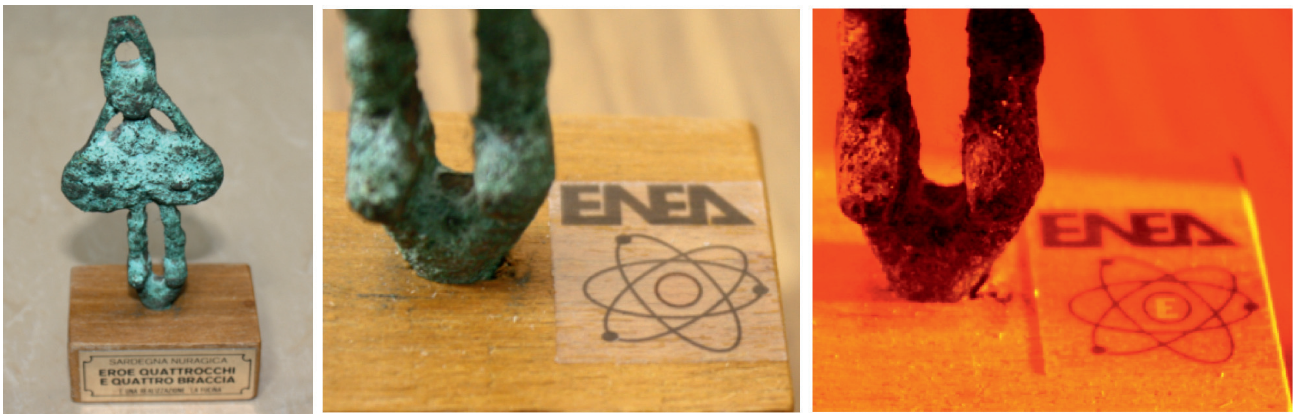

FIGURE 7 Left: copy of an archaeological bronze statue, known as “hero four-eyes and four-arms”. Height: 11 cm. Middle: the transparent and adhesive tag of Fig. 5 stuck on the wood base of the statue. Right: the letter ‘E’ patterned by EUV radiation appears when using the patented reading technique
Source: ENEA

with a variable thickness, as detailed in [10].
The feasibility of the application of this technology to artworks has been demonstrated, see Figs. 5 to 7.
Our anti-counterfeiting tags are resistant to normal conditions of use, and can be protected by a standard thermoplastic film, when exposed to severe conditions.
Our tags cannot be detached from the original object and stuck on another object, because in this case the pattern becomes visible, see Fig. 6.
Conservative estimations show that assembling the writing system by using commercially available parts, a production of about 50-100 tags/hour can be achieved.
The ENEA technology can be used alone or in conjunction with other anti-counterfeiting/tracing methods.
The level of security of our technology can be evaluated by the following standard criteria:

- very high cost to break;
- high probability to detect a clone;
- very low probability of false negatives;
- no privacy risks.

Concerning vulnerabilities, at the moment we are not able to find practical ways to fool the product authentication.
ENEA is presently looking for industrial companies and research partners interested in a joint scientific/engineering development, and/or license agreement, and/or testing new applications.

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